TP 14151E

Relationship Between Visibility and Snowfall Intensity

Prepared for

Transportation Development Centre
On behalf of
Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

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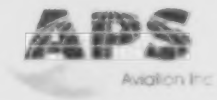

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by
Stephanie Bendickson

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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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Un sommaire français se trouve avant la table des matières.

PREFACE

Under contract to the Transportation Development Centre of Transport Canada and in conjunction with the Federal Aviation Administration, APS Aviation Inc. (APS) has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time data for all newly qualified de/anti-icing fluids;
- To evaluate the parameters specified in Proposed Aerospace Standard 5485 for frost endurance time tests in a laboratory;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To further evaluate the flow of contaminated fluid from the wing of an aircraft during simulated takeoff runs;
- To compare endurance times in natural snow with those in laboratory snow;
- To compare fluid endurance time, holdover time and protection time;
- To compare snowfall rates obtained using the National Center for Atmospheric Research hotplate with rates obtained using rate pans;
- To further analyse the relationship between snowfall rate and visibility;
- To stimulate the development of Type III fluids;
- To measure endurance times of fluids applied using forced air-assist systems;
- To conduct exploratory research, including measuring temperatures of applied Type IV fluids, measuring the effect of lag time on holdover time, evaluating the effectiveness of fluid coverage, and assessing the impact of taxi time on deicing holdover time; and
- To provide support services to Transport Canada.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2002-03 are documented in thirteen reports. The titles of the reports are as follows:

- TP 14144E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter;
- TP 14145E Laboratory Test Parameters for Frost Endurance Time Tests;
- TP 14146E Winter Weather Impact on Holdover Time Table Format (1995-2003);
- TP 14147E Aircraft Takeoff Test Program for Winter 2002-03: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid;
- TP 14148E Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2002-03;
- TP 14149E Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces;

- TP 14150E Evaluation of a Real-Time Snow Precipitation Gauge for Aircraft Deicing Operations;
- TP 14151E Relationship Between Visibility and Snowfall Intensity;
- TP 14152E A Potential Solution for De/Anti-Icing of Commuter Aircraft;
- TP 14153E Endurance Times of Fluids Applied with Forced Air Systems;
- TP 14154E Aircraft Ground Icing Exploratory Research for the 2002-03 Winter;
- TP 14155E Aircraft Ground Icing Research Support Activities for the 2002-03 Winter; and
- TP 14156E Variance in Endurance Times of De/Anti-Icing Fluids.

This report, TP 14151E, has the following objectives:

- To harmonize the Transport Canada and Federal Aviation Administration Type I fluid holdover time tables and visibility tables; and
- To determine the visibility range corresponding to very light snow.

To satisfy this objective, snowfall rate and visibility data from seven winter test seasons (1995-96 to 2001-02) were analyzed.

ACKNOWLEDGEMENTS

This research has been funded by Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Civil Aviation Group and the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Federal Express, American Eagle Airlines Inc., the National Center for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, Ottawa International Airport Authority, GlobeGround North America, and Dow Chemical Company for provision of personnel and facilities and for their co-operation with the test program. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Alia Alwaid, Stephanie Bendickson, Nicolas Blais, Richard Campbell, Mike Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Caroline Duclos, Miljana Horvat, Luis Lopez, Bob MacCallum, Mark Mayodon, Chris McCormack, Nicoara Moc, Marco Ruggi, Sherry Silliker, Ben Slater, and Kim Vepsa.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Thirteen reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

Under contract to the Transportation Development Centre of Transport Canada (TC), APS Aviation Inc. (APS) undertook a research program, co-sponsored by the Federal Aviation Administration (FAA), to analyse the relationship between snowfall intensity and visibility. The objectives of the research program were to harmonize the TC and FAA visibility tables and to find visibility ranges to correspond with the newly added *very light snow* category.

A database of visibility and precipitation rate data was constructed with rate data obtained from rates measured by APS using precipitation pans during endurance time testing, and visibility data obtained from the Meteorological Service of Canada automated weather station adjacent to the APS test site. The resulting data set, representing 700 hours of data, was compared to previous observations of the relationship between visibility and snowfall intensity made by the National Center for Atmospheric Research in Boulder, Colorado. The data sets were similar. Examination of the data set also confirmed that visibility at warmer temperatures (above -1°C) is more variable and tends to be higher than visibility at colder temperatures, likely due to the presence of wet snow.

TC and the FAA adopted new values for their 2003-04 visibility tables. The new visibility table values were selected to minimize snowfall intensity underestimation, which causes holdover times to be overestimated. The probability of underestimating snowfall intensity using the 2003-04 TC visibility table ranged from 0.6 percent to 11.1 percent, depending on the precipitation condition and temperature.

The 2003-04 TC and FAA visibility tables are much more similar than were the 2002-03 tables; however, more work is required to further harmonize the Type I holdover time tables. Recommendations also include researching alternate methods of estimating snowfall intensity and harmonizing nighttime measurements taken by visibility instruments in Canada and the United States.

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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers anténeurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de la saison hivernale a donné lieu à treize rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

À la demande du Centre de développement des transports de Transports Canada (TC), APS Aviation Inc. (APS) a entrepris un programme de recherche, coparrainé par la Federal Aviation Administration (FAA), visant à approfondir la relation entre l'intensité des chutes de neige et la visibilité. Ce programme de recherche avait pour objectifs d'harmoniser les tableaux de visibilité de TC et de la FAA, et d'établir les distances de visibilité pour la nouvelle catégorie de *neige très légère*.

Une base de données de visibilité et de taux de précipitation a été constituée, à partir, pour les uns, des taux de précipitation mesurés par APS dans les bacs à précipitations utilisés lors de ses essais de durée d'efficacité, et, pour les autres, des données de visibilité recueillies par la station météorologique automatisée du Service météorologique du Canada adjacente au site d'essai d'APS. Cette base de données, issue de 700 heures de collecte, a été comparée aux observations de la relation entre la visibilité et l'intensité des chutes de neige faites antérieurement par le National Center for Atmospheric Research à Boulder, au Colorado. Les deux ensembles de données se sont avérés semblables. L'examen de la base de données a en outre confirmé que la visibilité est plus variable et a tendance à être meilleure aux températures élevées (plus de -1 °C) qu'aux températures plus froides, probablement en raison de la présence de neige mouillée.

TC et la FAA ont révisé leurs tableaux de visibilité de l'hiver 2003-2004. Les nouvelles valeurs ont été choisies de façon à prévenir toute sous-estimation de l'intensité des chutes de neige, qui mène à surestimer les durées d'efficacité. Ainsi, la probabilité de sous-estimer l'intensité de la neige en se fiant au tableau de visibilité 2003-2004 de TC était de l'ordre de 0,6 p. 100 à 11,1 p. 100, selon la force des précipitations et la température.

Les tableaux de visibilité 2003-2004 de TC et de la FAA se ressemblent beaucoup plus que les tableaux 2002-2003. Il reste toutefois, selon les auteurs, à harmoniser les tableaux des durées d'efficacité des liquides de type I. Ils recommandent aussi d'élaborer de nouvelles méthodes pour évaluer l'intensité d'une chute de neige et d'harmoniser les mesures nocturnes prises par les instruments de mesure de la visibilité utilisés respectivement au Canada et aux États-Unis.

17. Mots clés	18. Diffusion
Dégivrage, antigivrage, durées d'efficacité, neige, visibilité, tableau de visibilité, intensité des chutes de neige	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

In an attempt to harmonize the Transport Canada (TC) and Federal Aviation Administration (FAA) Type I fluid holdover time guidelines, the visibility tables of the two governing bodies were examined. The tables were found to be quite different, resulting in the need for further analysis.

At the same time, a decision was made to add a *very light snow* column to the Type I fluid holdover guidelines for the 2003-04 winter. This meant that a *very light snow* column also had to be added to the visibility tables and that a visibility range corresponding to very light snow needed to be developed.

A database of visibility and rate data from seven winters was constructed to further investigate the visibility vs. snowfall rate relationship. Rate data was obtained from rates measured by APS using precipitation pans during endurance time testing. Visibility data was obtained from the Meteorological Service of Canada automated weather station located adjacent to the APS test site.

The resulting data set was compared to previous limited observations made in Boulder, Colorado by the National Center for Atmospheric Research. The data sets were found to be similar.

The 2002-03 TC and FAA visibility tables were different because TC applied a factor of two to the visibility table values in order to approximate snow catch on aircraft wings. When compared to the APS database, the visibility values in the existing TC table were found to be too high. The FAA visibility values were generally a better representation of the visibility rate relationship; however, in the colder temperature category the numbers were somewhat low.

Analysis confirmed that visibility at warmer temperatures (above -1°C) is more variable and tends to be higher than visibility at lower temperatures. This is likely due to the presence of wet snow.

Automated visibility measurements in Canada and the United States are different at night because instruments in the United States apply an algorithm to nighttime values in order to approximate nighttime visibilities as measured by the human eye, which can see approximately twice as far at night than in the day. Therefore, in the United States, the visibility table must specify lighting conditions, as visibility in the same snowfall intensity level will be different in darkness and in daylight. In Canada, the algorithm is not used. However, because human observers are used at some airports, there remain times when visibility is different during the night, relative to visibility in the same snowfall intensity during the day.

TC adopted new visibility table values for use in the winter of 2003-04. These values are shown in Table 1. The FAA adopted similar values for its 2003-04 visibility table, shown in Table 2. Visibility ranges for very light snow in different temperatures and lighting conditions were developed and are shown in the tables.

Table 1: Visibility in Snow vs. Snowfall Intensity (TC 2003-04)

Lighting	Temperature Range		Visibility in Snow (Statute Miles)			
	°C	°F	Heavy	Moderate	Light	Very Light
Darkness	-1 and above	30 and above	≤1	>1 to 2½	>2½ to 4	>4
	Below -1	Below 30	≤3/4	>3/4 to 1½	>1½ to 3	>3
Daylight	-1 and above	30 and above	≤½	>½ to 1½	>1½ to 3	>3
	Below -1	Below 30	≤3/8	>3/8 to 7/8	>7/8 to 2	>2

Table 2: Snowfall Intensities as a Function of Visibility (FAA 2003-04)

Time of Day	Temp. (°C)	Temp. (°F)	Visibility (Statute Mile) ≥2 1/2	2	1 1/2	1	3/4	1/2	≤1/4	
Day	colder/equal -1	colder/equal 30	Very Light	Very Light	Light	Light	Moderate	Moderate	**Heavy**	Snowfall Intensity
	warmer than -1	warmer than 30	Very Light	Light	Light	Moderate	Moderate	**Heavy**	**Heavy**	
Night	colder/equal -1	colder/equal 30	Very Light	Light	Moderate	Moderate	**Heavy**	**Heavy**	**Heavy**	
	warmer than -1	warmer than 30	Very Light	Light	Moderate	**Heavy**	**Heavy**	**Heavy**	**Heavy**	

NOTE: **Based upon technical report, "The Estimation of Snowfall Rate Using Visibility," Rasmussen, et al., Journal of Applied Meteorology, October 1999 and additional insitu data.**

HEAVY = Caution - no holdover time guidelines exist

The visibility table adopted by TC was constructed to minimize the underestimation of snowfall intensity. The probability of underestimating snowfall intensity was calculated for each visibility range in the table, excluding the heavy snow cells. These probabilities ranged from 0.6 percent to 11 percent.

Future recommendations include harmonizing the format of the visibility tables, harmonizing the Type I fluid holdover time tables, finding improved methods of estimating snowfall intensity, and harmonizing nighttime measurements taken by visibility instruments in Canada and the United States.

SOMMAIRE

Dans une tentative d'harmoniser les tableaux des durées d'efficacité des liquides de type I publiés par Transports Canada (TC) et la Federal Aviation Administration (FAA), les chercheurs ont examiné les tableaux de visibilité des deux organismes. Ayant constaté que ces tableaux étaient passablement différents, ils ont poussé leur analyse.

Au même moment, la décision était prise d'ajouter une colonne *neige très légère* aux tableaux des durées d'efficacité des liquides de type I pour l'hiver 2003-2004. Il fallait donc ajouter aussi une colonne *neige très légère* aux tableaux de visibilité, et élaborer des valeurs de visibilité correspondant à cette nouvelle catégorie.

Une base de données de visibilité et de taux de précipitation, constituée à partir de mesures prises pendant sept hivers, a servi à approfondir la relation entre la visibilité et le taux de précipitations neigeuses. Les données de précipitations ont été établies à partir des taux mesurés par APS dans les bacs à précipitations utilisés pour les essais de durée d'efficacité. Quant aux données de visibilité, elles ont été recueillies par la station météorologique automatisée du Service météorologique du Canada adjacente au site d'essai d'APS.

La base de données a été comparée au nombre limité d'observations de la relation entre la visibilité et l'intensité des chutes de neige, faites antérieurement par le National Center for Atmospheric Research à Boulder, au Colorado. Les deux ensembles de données se sont avérés semblables.

Les tableaux de visibilité 2002-2003 de TC et de la FAA différaient l'un de l'autre parce que TC appliquait un facteur de deux aux valeurs du tableau de visibilité, pour tenir compte du piégeage de la neige sur les ailes d'avions. Comparativement aux valeurs de la base de données d'APS, les valeurs du tableau de TC étaient trop élevées. Quant aux valeurs de la FAA, elles constituaient généralement une meilleure représentation de la relation entre la visibilité et l'intensité des précipitations; toutefois, aux faibles températures, les valeurs étaient plutôt faibles.

L'analyse a confirmé que la visibilité est plus variable et qu'elle a tendance à être meilleure aux températures élevées (au-dessus de -1 °C) qu'aux températures plus froides, probablement en raison de la présence de neige mouillée.

Les mesures automatisées de la visibilité nocturne faites au Canada diffèrent de celles des États-Unis, car les instruments utilisés aux États-Unis appliquent un algorithme qui tient compte de la capacité de l'œil humain de voir environ deux fois plus loin la nuit que le jour. C'est pourquoi le tableau de visibilité de FAA

précise les conditions d'éclairage ambiant, car sous une même intensité de précipitations, la visibilité ne sera pas la même selon qu'il fait jour ou qu'il fait nuit. Au Canada, on n'utilise pas un tel algorithme. Toutefois, comme certains aéroports ont recours à des observateurs humains, il arrive que l'on constate un écart entre la visibilité de jour et la visibilité de nuit, pour la même intensité de précipitations.

TC a adopté de nouvelles valeurs de visibilité pour son tableau de l'hiver 2003-2004. On trouve ces valeurs au tableau 1. La FAA a adopté des valeurs semblables pour son tableau de visibilité de l'hiver 2003-2004 (voir le tableau 2). Les distances de visibilité dans des conditions de neige très légère à différentes températures et dans différentes conditions d'éclairage ambiant ont aussi été déterminées et intégrées aux tableaux.

Tableau 1 : Visibilité dans la neige par rapport à l'intensité des précipitations (TC 2003-2004)

Éclairage ambiant	Plage de températures		Visibilité par température neigeuse (en milles terrestres)			
	°C	°F	Fortes	Modérées	Légères	Très légères
Obscurité	-1 et au-dessus	30 et au-dessus	≤1	>1 à 2½	>2½ à 4	>4
	Au-dessous de 1	Au-dessous de 30	≤3/4	>3/4 à 1½	>1½ à 3	>3
Lumière du jour	-1 et au-dessus	30 et au-dessus	≤½	>½ à 1½	>1½ à 3	>3
	Au-dessous de -1	Au-dessous de 30	≤3/8	>3/8 à 7/8	>7/8 à 2	>2

Tableau 2 : Intensité des précipitations de neige en fonction de la visibilité (FAA 2003-2004)

Moment du jour	Température (°C)	Température (°F)	Visibilité (en milles terrestres) ≥2 1/2	2	1 1/2	1	3/4	1/2	≤1/4	Intensité des précipitations
Jour	-1 et au-dessous	30 et au-dessous	Très légères	Très légères	Légères	Légères	Modérées	Modérées	**Fortes**	
	Au-dessus de -1	Au-dessus de 30	Très légères	Légères	Légères	Modérées	Modérées	**Fortes**	**Fortes**	
Nuit	-1 et au-dessous	30 et au-dessous	Très légères	Légères	Modérées	Modérées	**Fortes**	**Fortes**	**Fortes**	
	Au-dessus de -1	Au-dessus de 30	Très légères	Légères	Modérées	**Fortes**	**Fortes**	**Fortes**	**Fortes**	

NOTA : D'après le rapport «The Estimation of Snowfall Rate Using Visibility», Rasmussen, et al., Journal of Applied Meteorology, October 1999, et données additionnelles *in situ*

FORTES = ATTENTION - aucune ligne directrice sur les durées d'efficacité

Le tableau de visibilité adopté par TC a été établi de façon à éviter que l'on sous-estime l'intensité des chutes de neige. La probabilité d'une telle sous-estimation a été calculée pour chaque distance de visibilité du tableau, sauf pour les cellules de fortes précipitations. Ces probabilités variaient de 0,6 p. 100 à 11 p. 100.

Pour l'avenir, les auteurs recommandent d'axer les travaux sur l'harmonisation du format des tableaux de visibilité, l'harmonisation des tableaux des durées d'efficacité des liquides de type I, la mise au point de meilleures méthodes pour évaluer l'intensité des chutes de neige, et l'harmonisation des mesures nocturnes prises par les instruments de mesure de la visibilité au Canada et aux États-Unis.

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GLOSSARY

APS	APS Aviation Inc.
MSC	Meteorological Service of Canada
FAA	Federal Aviation Administration
METAR	Meteorological Aviation Report
NCAR	National Center for Atmospheric Research
OAT	Outside Air Temperature
TC	Transport Canada

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1. INTRODUCTION

Recent work at Transport Canada (TC) and the Federal Aviation Administration (FAA) has focussed on harmonizing winter weather guidelines for pilots, including harmonizing fluid holdover time guidelines. Holdover time guidelines provide pilots with times during which de/anti-icing fluids provide protection to aircraft wings after they have been cleaned of contaminating winter precipitation.

In the process of harmonizing the Type I fluid holdover time guidelines, the underlying visibility tables were examined. Visibility tables direct users to the appropriate column of the Type I fluid holdover time table during snow precipitation conditions. Depending on the visibility, users will be guided to the *light snow, moderate snow* or *heavy snow* column. As holdover times for different snowfall intensities vary considerably, using different visibility table values can result in very different holdover times.

1.1 Objectives

The scope of work for this project is outlined in an excerpt from the Transportation Development Centre work statement provided in Appendix A.

This project had two major objectives. The first objective was to harmonize the TC and FAA Type I fluid holdover time and visibility tables. This report documents changes made to the visibility tables only. Changes made to the Type I fluid holdover time tables are addressed in the TC reports TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter* (1) and TP 14146E, *Winter Weather Impact on Holdover Time Table Format (1995-2003)* (2).

The second objective was to determine visibility ranges corresponding to very light snow. A *very light snow* column was added to the Type I fluid holdover time guidelines for use in the 2003-04 winter. In order to use this column, a visibility range corresponding to very light snow had to be added to the visibility tables.

1.2 Operational Concerns with the Visibility Tables

In addition to harmonizing the Type I fluid holdover time guidelines and finding visibility ranges for very light snow, the visibility tables were also examined to address operational concerns. These concerns, which were voiced by a number of industry members, stemmed from discrepancies between snowfall intensity as measured by the 2002-03 visibility tables and as reported by the

Meteorological Aviation Reports (METAR). METAR also uses visibility to estimate snowfall intensity; however, it defines the intensity levels as:

a) Light snow: greater than or equal to 1 km;
b) Moderate snow: 0.5 to less than 1 km; and
c) Heavy snow: less than 0.5 km.

Unlike the visibility tables, these definitions are the same irrespective of lighting condition and outside air temperature (OAT).

Industry members reported situations in which METAR reported light snow when the visibility table indicated heavy snow. These discrepancies have led to an overall lack of confidence in the validity of the visibility tables.

1.3 Why the Tables are Different

In the late 1990s, work on the relationship between snowfall intensity and visibility was published in both the Journal of Applied Meteorology (3) and in the TC report, TP 12893, *Theoretical Considerations in the Estimation of Snowfall Rate Using Visibility* (4). Soon after, TC and the FAA included, for the first time, visibility tables as part of their holdover time guidelines. Prior to this, the only information available to pilots was METAR data.

Although they were based on the same research, there were differences between the TC report and the Journal of Applied Meteorology article. In the TC report, a factor of two was applied to the visibility table values in order to compensate for wind. The reasoning behind this was the theory that wind increases the amount of snow that lands on a wing (snow catch) relative to the amount of snow that lands on the ground (snow rate) by a factor of approximately two.

Because the TC table was based on the TC report, and the FAA table was based on the Journal of Meteorology article, differences existed between the TC and FAA tables. There are two reasons for the differences:

a) TC added a factor to account for wind; and,

b) The numbers were presented in different table formats and were rounded to facilitate usability.

1.4 Differences Between the TC and FAA Visibility Tables

The TC and FAA visibility tables used by operators in the winter of 2002-03 are shown in Tables 1.1 and 1.2. For most conditions, visibility values in the TC table are approximately double those in the FAA table.

Table 1.1: Visibility in Snow vs. Snowfall Intensity[1] (Used by TC for 2002-03 Winter Operations)

Lighting	Temperature Range		Visibility in Snow (Statute Miles)		
	°C	°F	Heavy[2]	Moderate[2]	Light[2]
Darkness	-1 and above	30 and above	<2	2 – 4	>4
	Below -1	Below 30	<1	1 – 2 1/2	>2 1/2
Daylight	-1 and above	30 and above	<1	1 – 2	>2
	Below -1	Below 30	<1/2	1/2 – 1 1/4	>1 1/4

1 National Center for Atmospheric Research, *Theoretical Considerations in the Estimation of Snowfall Rate Using Visibility* (TP 12893E), Transportation Development Centre, Transport Canada, November 1998.

2 Heavy snowfall intensity is defined as greater than **2.5 mm/hr equivalent liquid water precipitation**, moderate snow as **1 mm/hr** to **2.5 mm/hr**, and light snow as less than **1 mm/hr**.

Table 1.2: Snowfall Intensities as a Function of Visibility (Used by the FAA for 2002-03 Winter Operations)

Time of Day	Temp. (°C)	Visibility (Statute Mile)					
		≥1 1/4	1	3/4	1/2	≤1/4	
Day	≤ -1	Light	Light	Light	Moderate	**Heavy**	Snowfall Intensity
	> -1	Light	Light	Moderate	**Heavy**	**Heavy**	
Night	≤ -1	Light	Light	Moderate	**Heavy**	**Heavy**	
	> -1	Light	Moderate	**Heavy**	**Heavy**	**Heavy**	

NOTE: Based upon technical report, "The Estimation of Snowfall Rate Using Visibility," Rasmussen, et al., Journal of Applied Meteorology, October 1999.

In addition to having different values and a different format, the FAA table defines the colder condition as *less than or equal to -1°C* and the TC table defines it as *less than -1°C*. Furthermore, the FAA used the terminology *day* and *night* and TC uses the terminology *daylight* and *darkness* to refer to the two lighting conditions.

1.4.1 Illustration of Table Differences

The following scenario provides an example of the discrepancies that exist between the TC and FAA visibility tables.

Two pilots, a Canadian pilot following TC guidelines and an American pilot following FAA guidelines, check holdover times in the following condition:

a) OAT = -1°C;
b) Visibility = 0.75 miles (1.2 kilometres);
c) Lighting = daylight; and
d) Precipitation = snow.

The Canadian pilot, using the 2002-03 TC visibility table shown in Table 1.2, determines that snowfall intensity is heavy. The American pilot, using the 2002-03 FAA visibility table shown in Table 1.3, deduces that snowfall intensity is light. According to the 2002-03 holdover time guidelines (included in Appendix B) the Canadian pilot has no holdover time; however, the American pilot has a holdover time of 11 to 16 minutes.

This is one example of many significant differences that exist between the TC and FAA visibility tables. These differences are the reason for re-examining the visibility tables.

1.5 Initial Work

Initial work that explored differences between the two Type I fluid holdover time tables included an analysis of the winter 2001-02 Type I fluid endurance time tests conducted by APS Aviation Inc. (APS). Based on the pertinent variables for each of the precipitation rates measured in the winter of 2001-02, the analysis compared the holdover times that would be determined by TC and FAA guidelines. The differences were significant. A sample of this work is given in Table 1.3.

Further analysis revealed that a major factor contributing to the differences between TC and FAA holdover times was the underlying visibility tables. At this point the analysis was expanded to include rates measured during three previous winter test seasons. Snowfall intensities, as determined by the TC visibility table, the FAA visibility table, and the precipitation pan, were compared. The conclusion of this analysis was that in 355 of 2 683 cases, the FAA visibility table underestimated snowfall intensity and in 100 of 2 683 cases, the TC visibility table underestimated snowfall intensity.

Following this analysis it was determined necessary to expand the database to include all available rate measurement data. It was clear that there were significant differences between the visibility tables and that a thorough analysis would be necessary to support new values for the visibility tables. Furthermore, this analysis was required to support the values necessary for the new *very light snow* column.

Table 1.3: Sample Type I Fluid Endurance Time Comparison Analysis

Condition				Endurance Time (hr:min)	
OAT (°C)	Visibility (miles)	Visibility (kilometres)	Night/Day	TC	FAA
-8	5	8	night	0:06 - 0:13	0:06 - 0:10
-3	4	6.4	night	0:06 - 0:13	0:11 - 0:16
0	0.25	0.4	night	does not exist	does not exist
-7	0.75	1.2	day	0:02 - 0:04	0:06 - 0:10
-11	1	1.6	day	0:02 - 0:04	0:04 - 0:06
0	2.5	4	day	0:04 - 0:08	0:11 - 0:16
-11	4	6.4	night	0:04 - 0:08	0:04 - 0:06
-9	3	4.8	night	0:06 - 0:13	0:06 - 0:10
-4	0.25	0.4	day	does not exist	does not exist
-9	2.5	4	day	0:04 - 0:08	0:06 - 0:10
0	0.75	1.2	day	does not exist	0:06 - 0:11
1	1.5	2.4	day	0:02 - 0:04	0:11 - 0:16
-4	1.25	2	night	0:04 - 0:06	0:08 - 0:13
-3	1	1.6	night	0:04 - 0:06	0:11 - 0:16

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2. DESCRIPTION AND PROCESSING OF DATA

This section describes the method used for compiling field data and presents the complete data set.

2.1 Data Collection

A database was constructed using snowfall rate data obtained from endurance time testing performed by APS and visibility data obtained from the Meteorological Service of Canada (MSC).

2.1.1 Snowfall Intensity Data

Rates measured by APS were carried out using the standard precipitation pan collection method. All data was collected at the APS test site at Dorval Airport in Montreal using the procedure described in the TC report TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter* (1).

The procedure is designed to simulate the way that snow is caught on aircraft wings. Although it is referred to as a rate measurement, it is actually a measurement of snow-catch, and is more accurate in predicting snowfall on aircraft wings than are other methods of snow rate measurement. To simulate a wing, the 50 cm by 30 cm precipitation collection pan is faced into the wind at an angle of 10° during snow events and wetted with deicing fluid (see Photo 2.1).

The following excerpt from TP 14144E describes the procedure:

> *Two rate collection pans per test stand are used to determine precipitation rates in natural conditions. Prior to the rate collection period, both pans are marked (upper and lower), and the inner bottom and sides of the each pan are wetted with Type IV anti-icing fluid to prevent blowing snow from escaping the pan. The wetted pans are then weighed to the nearest 0.2 g. The start time of the rate collection period is recorded (hh:mm:ss) from the digital clock located near the rate station before the pans are brought outside the trailer.*
>
> *Two six-plate test stands are typically used during winter snow events. For each six-plate test stand, one rate collection pan is required. The pans are positioned at the extremities of the stands to collect precipitation for intervals of approximately 10 minutes in normal conditions and for*

5 minutes in periods of high precipitation rates and high winds. Before the precipitation pans are removed from the test stand and re-weighed, any accumulated precipitation on the lips and outer sides of each precipitation pan is carefully removed. The precipitation pans are then carried to the rate station to be re-weighed. Upon entering the trailer, the exact time is noted. The new weights of the precipitation pans are recorded and the pans are brought back outside.

2.1.2 Visibility Data

The MSC weather station in Montreal is located adjacent to the APS test site at Dorval Airport. MSC uses a Belfort Forward Scatter Meter to measure visibility (see Photo 2.2). The instrument uses the principle of forward scatter to measure visibility. A high output light transmitter projects a flash into a sample volume and light scattered in a forward direction is collected by a receiver. The light source is modulated to reject natural variations in background light intensity, and therefore neither darkness nor daylight has an effect on the instrument's readings. See Subsection 2.3 for further discussion on daytime and nighttime visibility.

The sensor takes a measurement every thirty seconds, but transmits a value once per minute. The visibility value transmitted is the average one-minute value from the preceding ten minutes. For this analysis, visibility measurements transmitted over the rate measurement time period skewed ahead five minutes were averaged to give a more representative average visibility value. See Figure 2.1 for a graphical representation of the measurement time period.

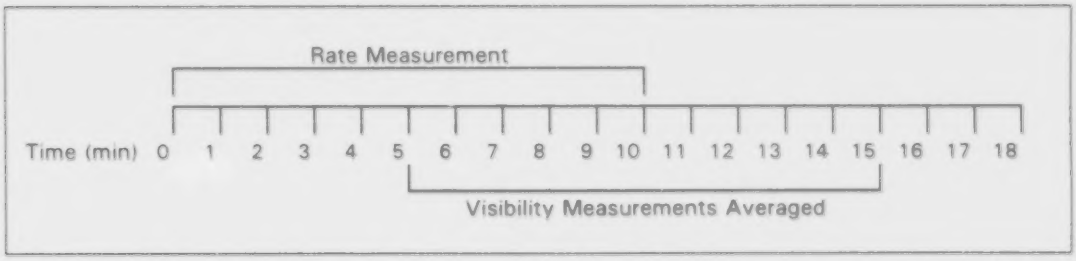

Figure 2.1: Visibility Measurement Collection Time Interval

It should be noted that in this report, all visibility data is presented in statute miles, not in kilometres. The reason for this is that miles are used in the visibility tables and therefore the analysis was performed in miles for consistency and accuracy.

2.2 Data Analysis

2.2.1 Data Analysis Process

The analysis of data involved a considerable amount of data processing, which was completed in several steps. First, rate measurements from previous test seasons had to be retrieved from APS archives. They then had to be matched with the visibility data obtained from MSC. This data also had to be de-archived. Special attention was taken to match test times to visibility data measurements as described in Subsection 2.1.2. Finally, tests taking place under precipitation conditions other than pure snow (freezing rain, rain, etc.) had to be removed. The removal of data points was done on a case-by-case basis.

2.2.2 Database

Each data point in the database represents one rate measurement of approximately twelve minutes in natural snow conditions. Table 2.1 shows the number of data points collected over each of the seven winters from which data was available.

Table 2.1: Data Points Collected by Winter Test Season

Winter	Data Points
1995-96	872
1996-97	1 122
1997-98	1 009
1998-99	1 530
1999-2000	1 308
2000-01	642
2001-02	556
Total	**7 039**

A total of 7 039 data points were included in the final database, representing approximately 700 hours of data. Each data point represents a rate measured in one precipitation plan. As described in the procedure, two precipitation pans were used simultaneously to measure rates and therefore, for the purposes of this calculation, the number of data points was halved to estimate the number of hours of data.

2.3 Daytime and Nighttime Visibility

The human eye can see almost twice as far at night as it can during the day. For example, if it is snowing at a rate of 15 g/dm²/h during the day, a person can see approximately one mile. If it is snowing at the same rate during the night, a person can see approximately two miles. It was therefore important to find out whether the measurements taken by the visibility instrument are affected by lighting condition, like the human eye, or if they are independent of lighting condition.

The Belfort Forward Scatter Meter is used to measure visibility in both Canada and the United States. The instrument has the capability to simulate a human observer by using an algorithm to adjust raw nighttime values to approximate nighttime values as seen by the human eye. In the United States, the instrument uses this algorithm and therefore the values reported by the instrument are approximately equal to values reported by a human observer in both lighting conditions.

In Canada, visibility instruments do not use the algorithm. Therefore, values reported by the instrument during the day are approximately equal to values reported by a human observer, but values reported by the instrument at night are approximately one half of the values reported by a human observer.

Table 2.2 provides a comparison of visibility measured in Canada and the United States by human observers and visibility instruments when the same snowfall rate is assumed.

Table 2.2: Visibility Measured by Human Observers and Visibility Instruments at a Rate of 15 g/dm²/h

	United States		Canada	
	Human Observer	Visibility Instrument	Human Observer	Visibility Instrument
Day	1 mile	1 mile	1 mile	1 mile
Night	2 miles	2 miles	2 miles	1 mile

Because the data acquired for this report was measured by a Belfort Forward Scatter Meter in Canada, all data represents daytime values.

2.3.1 Implications for Visibility Tables

In the United States, the visibility table must specify lighting conditions because visibility measurements made in the same snowfall intensity but different lighting conditions will be different.

In Canada, day and night must also be specified on the visibility table, but for different reasons. If the visibility instrument were the only method used to obtain visibilities, a Canadian visibility table would not have to specify lighting conditions because visibility measurements made in the same snowfall intensity would be the same irrespective of the lighting conditions. However, because human observers are used to measure visibility at some Canadian airports, there can be a difference between visibilities measured in the same snowfall intensity in different lighting conditions. Furthermore, pilots using the TC table also fly outside of Canada where differences may or may not exist between daytime and nighttime visibilities. Thus, day and night must also be specified in the TC visibility table. This causes the TC table to be more conservative at night when all visibility is measured with an instrument.

2.3.2 Implications for Pilots

Because there is extra conservatism built into the TC table, a pilot in Canada will sometimes obtain a shorter holdover time using visibilities from the instrument rather than measuring his or her own visibility. The following example illustrates this point. Table 2.2 shows how human observers and visibility instruments measure visibility at a rate of 15 g/dm²/h, which is moderate snow according to snowfall rate definitions of snowfall intensity.

Using these visibility values, in conjunction with the visibility table presented in Table 1.1, it can be deduced that in a situation where visibility is measured at night by an instrument in Canada, snowfall intensity would be considered heavy. However, when the same condition is reported in the United States, or when a human observer measures visibility in Canada, the snowfall intensity would be considered moderate. Therefore a pilot in Canada would obtain a shorter holdover time using the visibility reported by the instrument rather than measuring visibility with his or her own eye. Measuring visibility with the eye does not, and will not, represent a safety concern because the visibility instrument causes users to overestimate the true snowfall intensity. In Canada, using the visibility instrument at night will always classify snowfall intensity greater than or equal to snowfall intensity as classified by a human observer.

2.4 Snowfall Intensity Definitions

In the analysis of data, the definitions of snowfall intensity were followed as described in TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter* (1):

a) Heavy Snow: greater than 25 g/dm²/h;
b) Moderate Snow: 10 to 25 g/dm²/h;
c) Light Snow: 4 to 10 g/dm²/h; and
d) Very Light Snow: less than 4 g/dm²/h.

As described in Section 1, the *very light snow* classification is a recent addition to the snowfall intensity definitions. Visibility values that correspond with very light snow are given in Section 4.

2.5 Data Compilation

The complete visibility/rate data set is plotted in Figure 2.2. As is evidenced in this chart, the relationship between visibility and snowfall intensity is logarithmic. The boundaries of the snowfall intensities as defined in Subsection 2.4 are illustrated on the chart as vertical dashed lines.

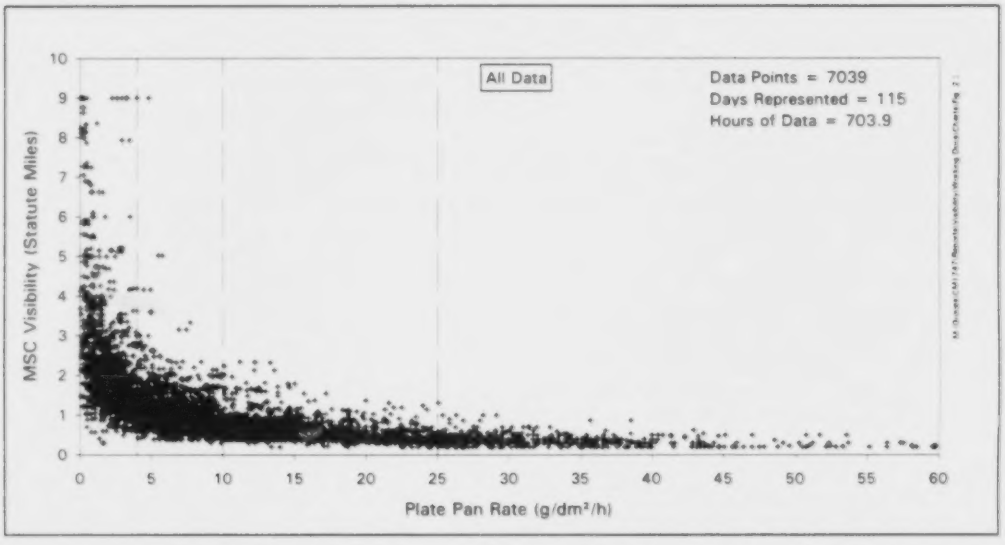

Figure 2.2: Visibility vs. Rate (1995-96 to 2001-02)

2.5.1 Visibility at Different Temperatures

The Journal of Meteorology article (3) established that visibility is greater in wet snow than in dry snow. Wet snow typically occurs in warmer temperatures; however, not all snow in warmer temperatures is wet. In order to investigate this phenomenon, the data set was split into data points below -1°C, shown in Figure 2.3, and data points above -1°C, shown in Figure 2.4. This is the same temperature division as the 2002-03 visibility tables.

As evidenced by the statistics presented in Table 2.3, visibility tends to be higher at warmer temperatures compared to colder temperatures. This trend is more noticeable at lower snowfall rates. As evidenced by Figures 2.4 and 2.5, visibility also has more variability at warmer temperatures.

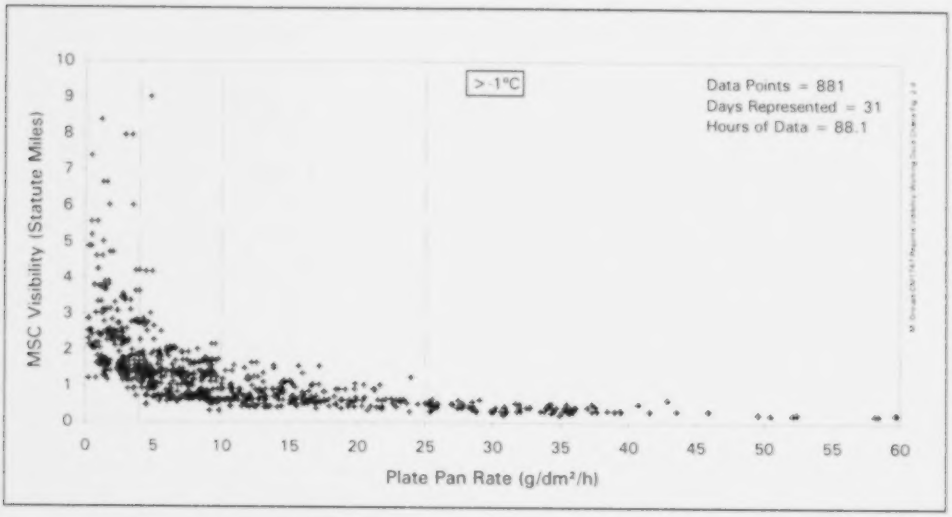

Figure 2.3: Visibility and Rate Data Below -1°C

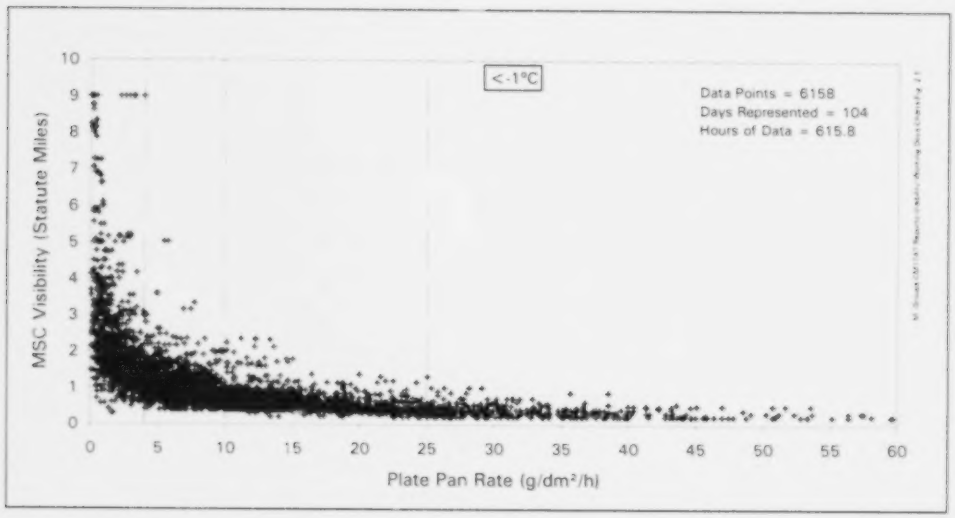

Figure 2.4: Visibility and Rate Data Above -1°C

Table 2.3: Average Visibility Above and Below -1°C

	Very Light Snow (<4 g/dm²/h)	Light Snow (4 to 10 g/dm²/h)	Moderate Snow (10 to 25 g/dm²/h)	Heavy Snow (>25 g/dm²/h)
Above -1°C	2.5 miles	1.3 miles	0.7 miles	0.4 miles
Below -1°C	2.1 miles	1.0 miles	0.6 miles	0.4 miles

It should be noted that there are many more data points (6 158 compared to 881) in the *below -1°C* chart compared to the *above -1°C* chart. This is not surprising, as most snow precipitation, and the majority of endurance time testing, occurs below -1°C. For detailed statistics refer to the TC report, TP 14146E, *Winter Weather Impact on Holdover Time Table Format (1995-2003)* (2).

2.5.2 Freezing Rain Data Points

A significant number of data points were eliminated from the database due to the presence of freezing rain. Visibility is higher in freezing rain than in natural snow at any given precipitation rate.

Figure 2.5 shows the database prior to the removal of the freezing rain data points, which are indicated as grey triangles. A total of 1 012 points were removed, leaving 7 039 data points for analysis.

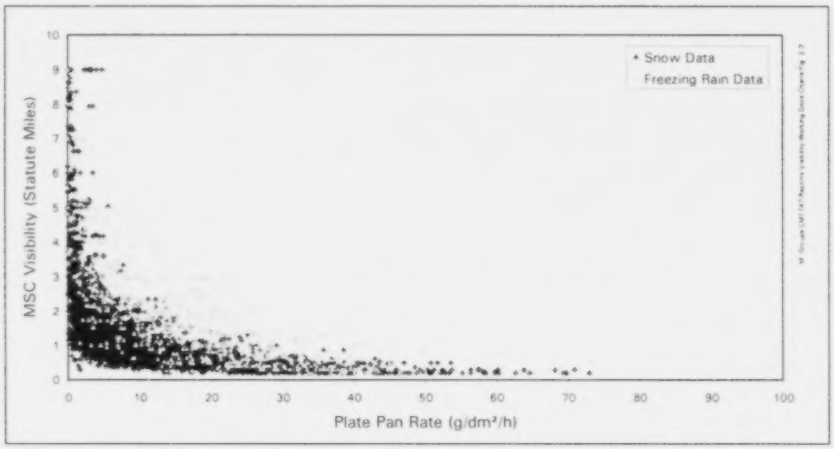

Figure 2.5: Removed Freezing Rain Data Points

2.6 Comparison to Boulder Data

Visibility and snowfall rate measurements collected at the National Center for Atmospheric Research (NCAR) Marshall Field test site during the winter of 1994-95 are presented in the TC report, TP 12893E, *Theoretical Considerations in the Estimation of Snowfall Rate Using Visibility* (4). The Marshall Field test site is located near Boulder, Colorado. An HSS VPF-730 visibility sensor was used to measure visibility and an ETI Instrument Systems 30 cm (12 in.) Automated Total Precipitation Rain and Snow Gauge set inside a Wyoming shield was used to measure snowfall rate.

The NCAR data set is compared to the APS data set in Figure 2.6. The data sets are similar. It should be noted that a snowfall rate of 1 mm/h is equivalent to 10 g/dm²/h.

It has been theorized that the snow catch on aircraft wings may be about double the snowfall rate measured using the NCAR method. As the APS snowfall rate collection method is designed to better simulate snowfall on aircraft wings, the APS measured rates are, on average, double NCAR rates in the same conditions. To investigate this theory, the NCAR rates have been doubled in Figure 2.7. The two data sets appear to be closer, although at higher rates the NCAR data exhibits more scatter.

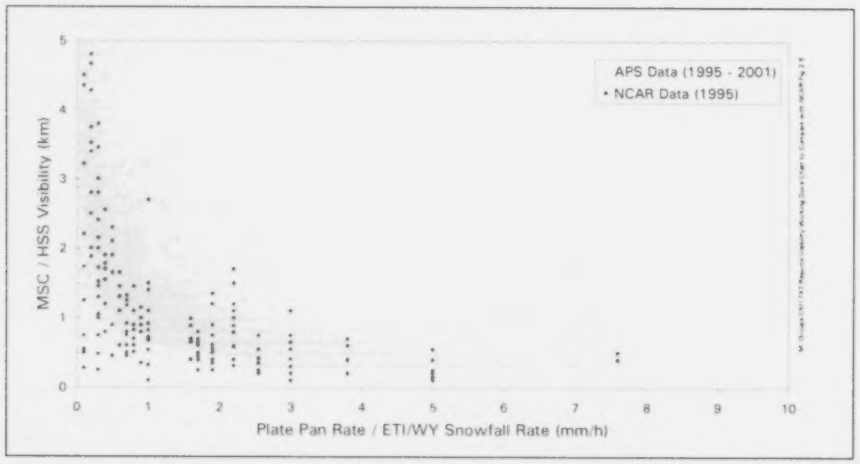

Figure 2.6: APS and NCAR Snowfall Rate and Visibility Data

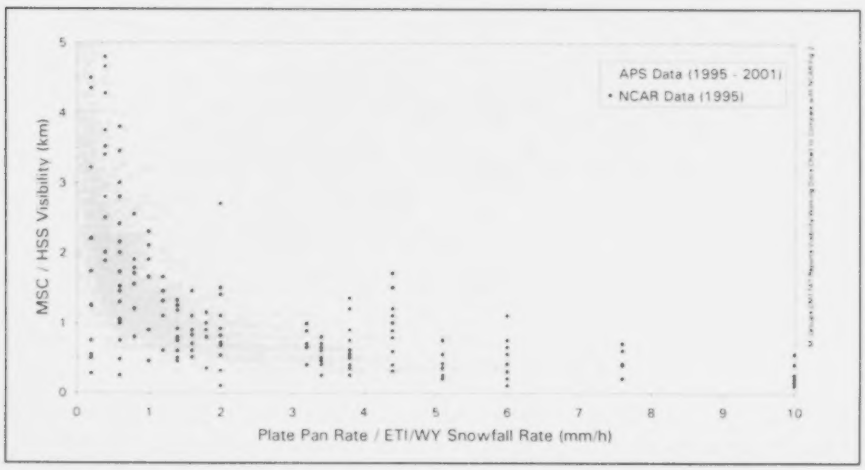

Figure 2.7: Figure 2.6 with NCAR Rates Shifted by a Factor of Two

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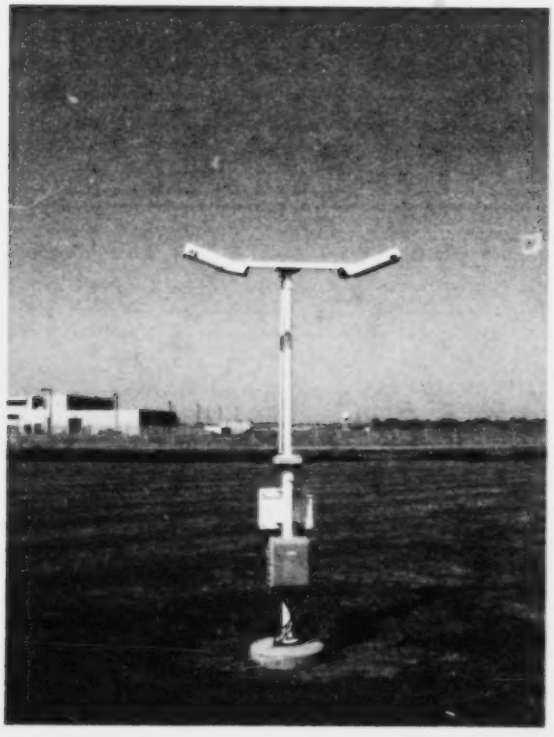
Photo 2.1: Precipitation Collection Pans

Photo 2.2: Belfort Forward Scatter Meter



3. NEW VISIBILITY TABLE VALUES

The process by which new visibility tables were created for 2003-04 is presented in this section.

3.1 Building a New Visibility Table

It is difficult to produce an accurate visibility table due to the difficulty inherent in representing a logarithmic relationship with linear divisions. Using the visibility table, the snowfall intensities for many data points will be either underestimated or overestimated. For safety reasons, it is preferable to overestimate rather than underestimate snowfall intensity because when snowfall is underestimated holdover times will be overestimated. This could lead to aircraft wings becoming contaminated with precipitation prior to the holdover times expiring.

Therefore, the numbers in the visibility table are chosen so that the majority of data points for a given snowfall intensity classification fall below the upper visibility limit for that snowfall intensity.

The probability of a given visibility measurement having a snowfall intensity greater than that indicated by the visibility table is examined in Subsection 3.7.

3.2 2002-03 Values

The values in the 2002-03 FAA and TC visibility tables are superimposed on log-log plots of the data set in Figures 3.1 and 3.2. Due to the format of the FAA table, there is some ambiguity as to where the FAA would place these boundaries; for the purposes of this analysis, the more conservative alternative was chosen when ambiguity existed.

Any data points that lie above the horizontal line in a given snowfall intensity range represent points where snowfall intensity would have been underestimated using the visibility tables. These points represent safety concerns and need to be minimized.

As illustrated in Figures 3.1 and 3.2, the visibility values in the TC table tend to be too high, which indicates that snowfall intensity is often overestimated using the TC table. The FAA visibility values are a better representation of the visibility rate relationship, but in the colder temperature classification they are somewhat low.

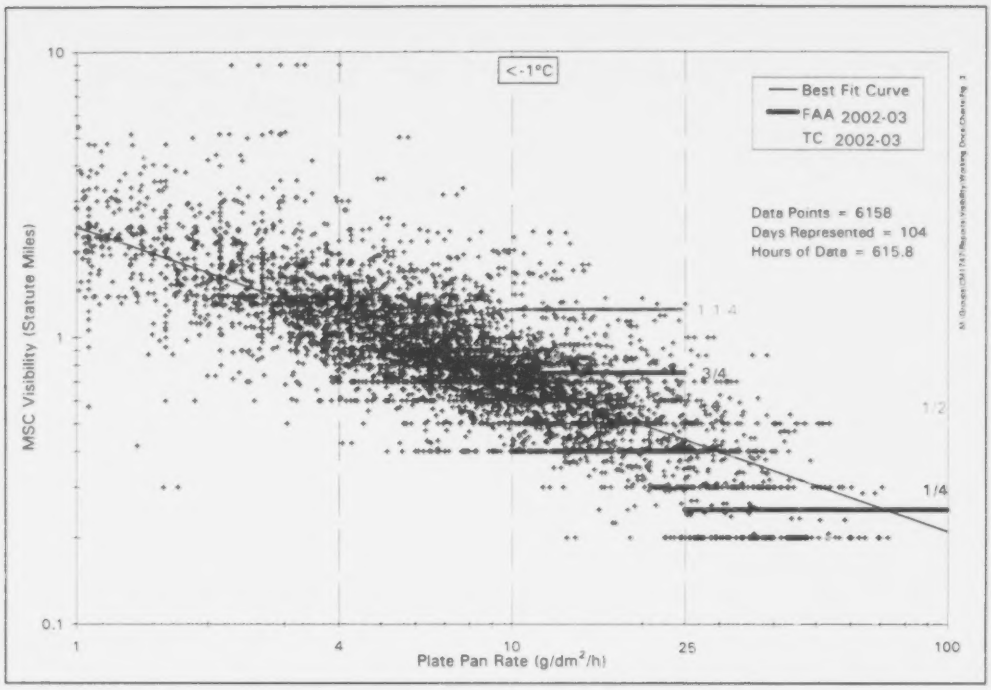


Figure 3.1: 2002-03 TC and FAA Visibility Boundaries – Below -1°C

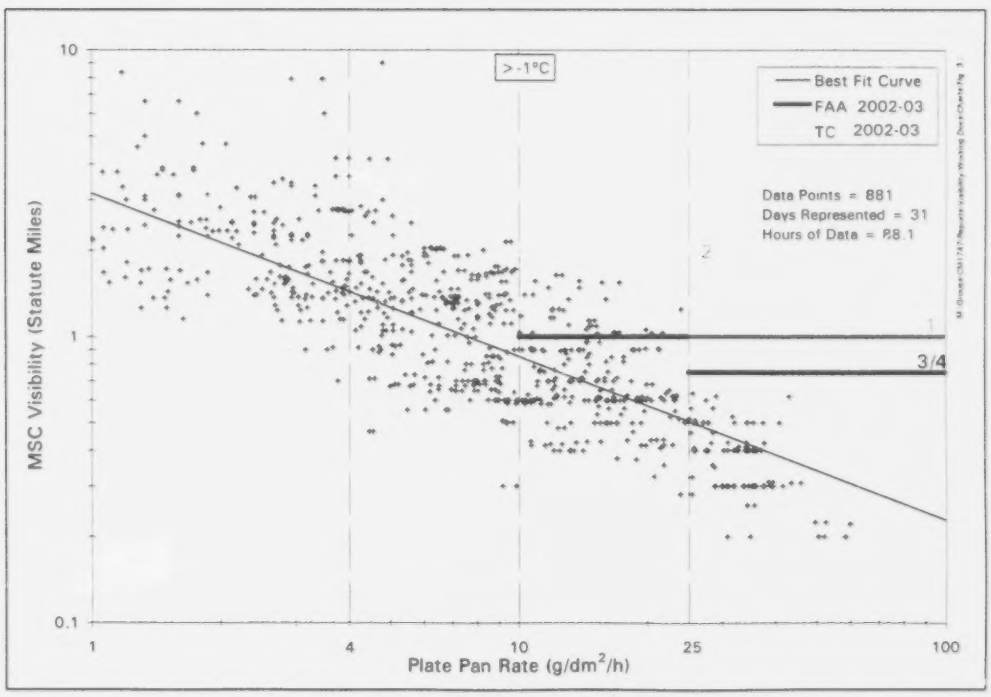


Figure 3.2: 2002-03 TC and FAA Visibility Boundaries – Above -1°C

3.3 Daytime Values

After initial analysis of the database, a meeting was held to discuss new values for the visibility tables. The meeting was attended by TC, the FAA and APS. Based on previous work and on an initial analysis of the new data, the daytime visibility ranges presented in Table 3.1 were tentatively agreed upon. Following the meeting, TC adopted these values.

Table 3.1: Daytime Visibility Values

Lighting	Temperature Range		Visibility in Snow (Statute Miles)			
	°C	°F	Heavy	Moderate	Light	Very Light
Daylight	-1 and above	30 and above	≤ ½	> ½ to 1 ½	> 1 ½ to 3	> 3
	Below -1	Below 30	≤ 3/8	> 3/8 to 7/8	> 7/8 to 2	> 2

3.4 Nighttime Values

As described in Subsection 2.3, the visibility table must show a distinction between day and night. Rasmussen et al. (2) deduced a formula for converting daytime visibility values to the equivalent human observer nighttime values. This formula is shown below.

$$V_d = \frac{\ln(E)V_n}{\ln(C_{DB}V_n/I_o)}$$

where

V_d = Daytime visibility
E = Visual contrast threshold
V_n = Nighttime visibility
C_{DB} = Constant of proportionality
I_o = Luminous intensity

This formula makes several assumptions, including:

a) $E = 0.055$;
b) $C_{DB} = 0.084$ mi^{-1}; and
c) $I_o = 25$ candles.

To generate values for the nighttime cells in the visibility table, the formula was applied to the values in the daytime cells. The numbers were rounded for usability (see Table 3.2).

Table 3.2: Nighttime Visibility Values

Lighting	Temperature Range		Visibility in Snow (Statute Miles)			
	°C	°F	Heavy	Moderate	Light	Very Light
Darkness	-1 and above	30 and above	≤ 1	> 1 to 2 ½	> 2 ½ to 4	> 4
	Below -1	Below 30	≤ 3/4	> 3/4 to 1 ½	> 1 ½ to 3	> 3

3.5 Final Table

The final visibility table with values for both daytime and nighttime is shown in Table 3.3.

Table 3.3: Visibility in Snow vs. Snowfall Intensity – Proposed 2003-04

Lighting	Temperature Range		Visibility in Snow (Statute Miles)			
	°C	°F	Heavy	Moderate	Light	Very Light
Darkness	-1 and above	30 and above	≤ 1	> 1 to 2 ½	> 2 ½ to 4	> 4
	Below -1	Below 30	≤ 3/4	> 3/4 to 1 ½	> 1 ½ to 3	> 3
Daylight	-1 and above	30 and above	≤ ½	> ½ to 1 ½	> 1 ½ to 3	> 3
	Below -1	Below 30	≤ 3/8	> 3/8 to 7/8	> 7/8 to 2	> 2

3.6 Comparison of 2002-03 and 2003-04 Tables

A comparison can be made between the accuracy of the 2002-03 and 2003-04 TC visibility tables by calculating the number of data points in the data set that are underestimated, classified accurately and overestimated for each table. These numbers have been calculated in Table 3.4. The 2003-04 visibility table shows a 12 percent increase in accurate points, 18 percent decrease in overestimated points and a 5 percent increase in underestimated points.

Table 3.4: Comparison of 2002-03 and 2003-04 Visibility Table Accuracy

Visibility Table	Data Points Underestimated	Data Points Classified Accurately	Data Points Overestimated
2002-03	2%	49%	50%
2003-04	7%	61%	32%

3.7 Further Statistical Analysis

Following the preliminary agreement on visibility table values, further analysis was performed on the database. In this subsection, the probability of underestimating snowfall intensity using the proposed visibility table is calculated. As noted in Subsection 3.1, snowfall intensity underestimation is a safety concern, which is why it is analyzed in this subsection. Nighttime values were derived from daytime values using an algorithm, and therefore only the daytime values are examined.

Using basic statistics, the probability of underestimating snowfall intensity can be calculated for each cell in the visibility table. Detailed calculations are presented in Appendix C. The probabilities are presented in Table 3.5. Calculations were also made to determine the probability that snowfall intensity would be underestimated by more than one classification (for example, heavy snow would be classified as light snow). All of these probabilities were 0 percent.

The cell in Table 3.5 containing 2.4 percent can be interpreted as follows: there is a 2.4 percent probability that when visibility is between 1.5 and 3 miles during the day and the OAT is above -1°C, snowfall intensity will be moderate, and there is 0 percent probability that it will be heavy.

The probabilities in Table 3.5 have been accepted as representing an adequate level of safety.

Table 3.5: Probability Snowfall Intensity is Greater than Predicted by the New Visibility Table

	Visibility (miles)	Predicted Snowfall Intensity	Probability Snowfall Intensity is Greater than Predicted
Above -1°C	≤ 1/2	Heavy	N/A
	> 1/2 to 1 1/2	Moderate	0.6%
	> 1 1/2 to 3	Light	2.4%*
	> 3	Very Light	5.1%*
Below -1°C	≤ 3/8	Heavy	N/A
	> 3/8 to 7/8	Moderate	3.5%
	> 7/8 to 2	Light	8.2%*
	> 2	Very Light	11.1%*

*In this case the probability of snowfall intensity being two categories greater than predicted is 0%.

3.8 Visibility Ranges for Very Light Snow

As shown in Table 3.3, visibility ranges for very light snow have been defined under four conditions:

a) Greater than 4 miles when OAT is -1°C or above, and it is dark;
b) Greater than 3 miles when OAT is -1°C or above, and it is light;
c) Greater than 3 miles when OAT is below -1°C, and it is dark; and
d) Greater than 2 miles when OAT is below -1°C and it is light.

3.9 Adoption of Proposed Visibility Table by TC and FAA

TC adopted Table 3.3 as its visibility table for 2003-04. The TC visibility ranges are illustrated graphically in Figures 3.3 and 3.4.

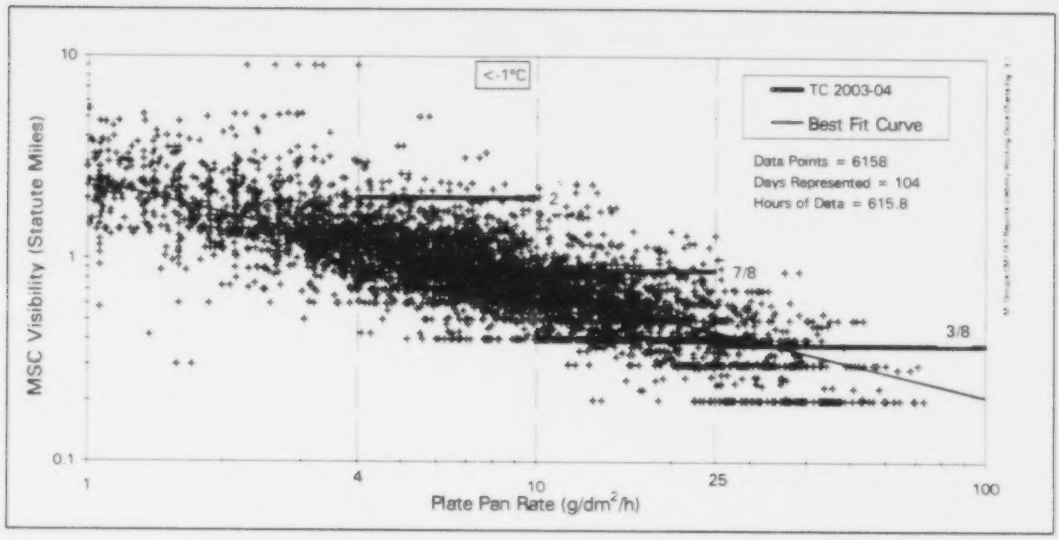


Figure 3.3: 2003-04 TC Visibility Boundaries – Below -1°C

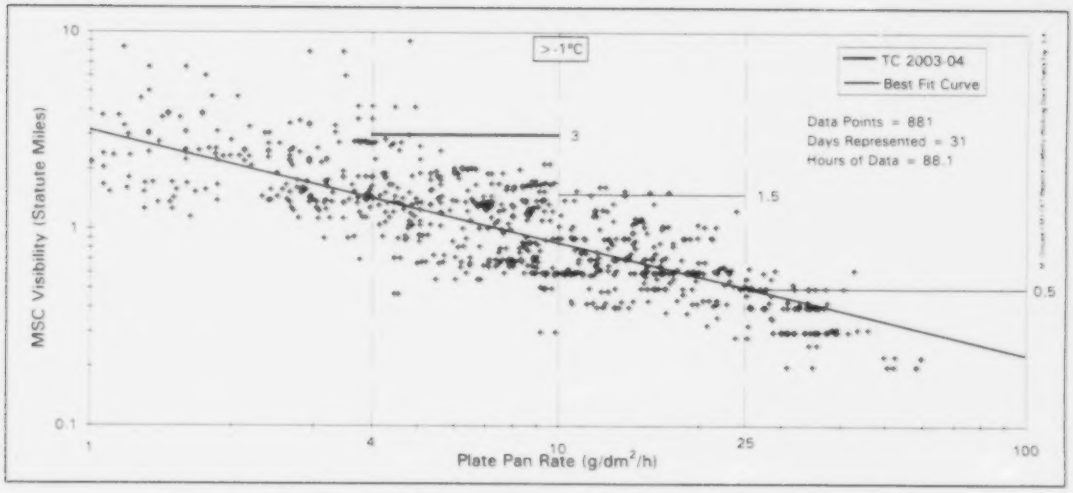


Figure 3.4: 2003-04 TC Visibility Boundaries – Above -1°C

The FAA elected to create a different table, shown in Table 3.6, for use in 2003-04. Although presented in different formats, the values in the tables are similar to those in the TC table. The FAA visibility ranges are illustrated graphically in Figures 3.5 and 3.6. As there is some ambiguity as to where the exact boundaries between snowfall intensities fall, a range has been indicated on the figures in order to include all possibilities.

The ambiguity present in the FAA table is a result of visibilities being presented as values and not ranges. Visibility measurements are normally given in quarter mile increments in the United States. However, when pilots from United States airlines fly outside of their country, they may encounter visibility measurements given in other units. For example, in Europe visibility measurements are reported in metres. Visibility tables should be usable anywhere that their users fly.

Table 3.6: Snowfall Intensities as a Function of Visibility (FAA 2003-04)

Time of Day	Temp. (°C)	Temp. (°F)	Visibility (Statute Mile) ≥2 1/2	2	1 1/2	1	3/4	1/2	≤1/4	
Day	colder equal -1	colder equal 30	Very Light	Very Light	Light	Light	Moderate	Moderate	**Heavy**	Snowfall Intensity
	warmer than -1	warmer than 30	Very Light	Light	Light	Moderate	Moderate	**Heavy**	**Heavy**	
Night	colder equal -1	colder equal 30	Very Light	Light	Moderate	Moderate	**Heavy**	**Heavy**	**Heavy**	
	warmer than -1	warmer than 30	Very Light	Light	Moderate	**Heavy**	**Heavy**	**Heavy**	**Heavy**	

NOTE: **Based upon technical report, "The Estimation of Snowfall Rate Using Visibility," Rasmussen, et al., Journal of Applied Meteorology, October 1999 and additional insitu data.**

HEAVY = Caution - no holdover time guidelines exist

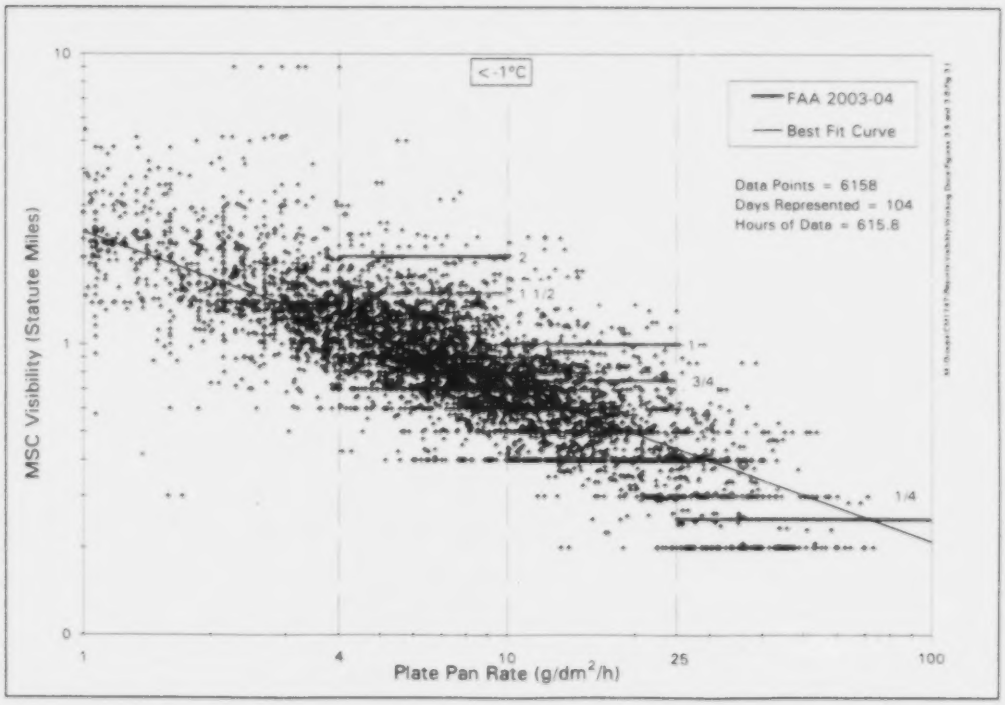


Figure 3.5: 2003-04 FAA Visibility Boundaries – Below -1°C

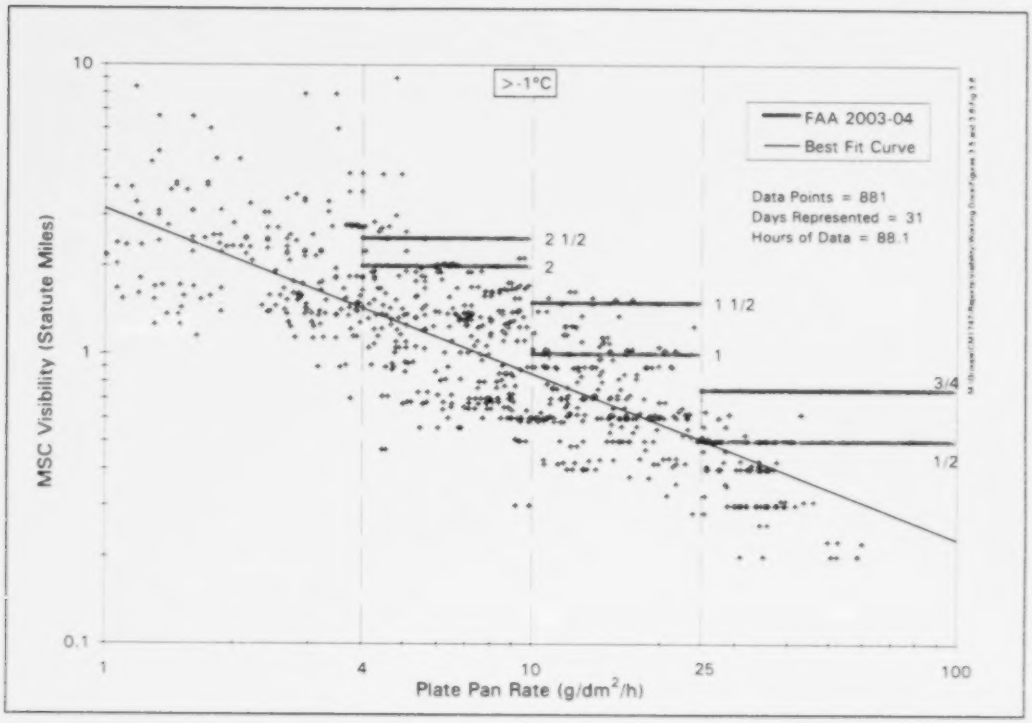


Figure 3.6: 2003-04 FAA Visibility Boundaries – Above -1°C

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4. CONCLUSIONS

Several conclusions can be drawn from the work completed for this project:

a) The visibility tables used by TC and the FAA in the winter of 2002-03 were different. Based on the analysis of a large database of visibility and snowfall intensity data, the TC table tended to overestimate snowfall intensity and the FAA table, although closer to the safe values, tended to underestimate snowfall intensity.

b) There is a difference in visibility in snow conditions in warmer and cooler temperatures. Visibility is higher and varies more in warmer temperatures, likely due to the presence of wet snow.

c) Visibility ranges for very light snow have been defined as follows:

- Greater than 4 miles when OAT is -1°C or above, and it is dark;
- Greater than 3 miles when OAT is -1°C or above, and it is light;
- Greater than 3 miles when OAT is below -1°C and it is dark; and
- Greater than 2 miles when OAT is below -1°C and it is light.

d) The visibility tables that TC and the FAA will use in 2003-04 winter operations are much more similar than were the tables used in previous winters. In harmonizing their visibility tables, TC and the FAA have provided improved and more consistent guidance to the industry. The primary difference that remains between the two tables is their format.

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5. RECOMMENDATIONS

The following are recommended:

a) Further work should be conducted in order to harmonize the formats of the TC and FAA visibility tables, and to harmonize the Type I fluid holdover time guidelines. The SAE G-12 Holdover Time workgroup may be an appropriate forum for discussing these changes.

b) As visibility and snowfall intensity are not perfectly correlated, there is the potential to find a more accurate method of predicting snowfall intensity. Emphasis should be placed on researching other methods of measuring snowfall intensity, including automated snowfall intensity measurement instruments.

c) The United States and Canada should harmonize measurements that come from automated visibility instruments. This could be accomplished either by the United States removing the algorithm it applies to nighttime measurements, or by Canada adding the algorithm to nighttime measurements.

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3. Rasmussen, R., Vivekanandan, J., Cole, J., Meyers, B., Masters, C., "The Estimation of Snowfall Rate Using Visibility", *Journal of Applied Meteorology*, Vol. 38, No. 10, October 1999.

4. Rasmussen, R., Vivekanandan, J., Cole, J., Karplus, E., *Theoretical Considerations in the Estimation of Snowfall Rate Using Visibility*, The National Center for Atmospheric Research, Transportation Development Centre, Boulder, November 1998, TP 12893E.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2002-03

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2002 -03

5.19 Visibility and Snowfall Rate Analysis

5.19.1 Analyze the current Transport Canada (TC) and Federal Aviation Administration (FAA) Type I holdover tables and summarize the differences between them;

5.19.2 Analyze the current TC and FAA visibility tables and summarize the differences between them;

5.19.3 Research current automated visibility sensors used by AWOS and ASOS;

5.19.4 Analyze rate and visibility data from eight previous winters;

5.19.5 Develop new harmonized holdover and visibility tables; and

5.19.6 Prepare a report.

APPENDIX B

FEDERAL AVIATION ADMINISTRATION AND TRANSPORT CANADA TYPE I HOLDOVER TIME (HOT) GUIDELINES WINTER 2002-03

Figure B-1: FAA TYPE I Holdover Time Guideline

Table 1. Guideline for Holdover Times Anticipated for SAE Type I Fluid Mixture as a Function of Weather Conditions and OAT.
CAUTION: THIS TABLE IS FOR DEPARTURE PLANNING ONLY AND SHOULD BE USED IN CONJUNCTION WITH PRE-TAKEOFF CHECK

OAT		Approximate Holdover Times Under Various Weather Conditions (hours: minutes)							
°C	°F	Frost*	Freezing Fog	Light Snow**	Moderate Snow**	**Freezing Drizzle	Light Freezing Rain	Rain on Cold Soaked Wing	Other‡
-3 and above	27 and above	0:45	0:11 - 0:17	0:11 - 0:16	0:06 - 0:11	0:09 - 0:13	0:02 - 0:05	0:02 - 0:05	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	0:45	0:08 - 0:14	0:08 - 0:13	0:05 - 0:08	0:07 - 0:10	0:02 - 0:05	CAUTION: Clear ice may require touch for confirmation	
-7 to -10	20 to 14	0:45	0:06 - 0:10	0:06 - 0:10	0:04 - 0:06	0:05 - 0:08	0:02 - 0:05		
Below -10	below 14	0:45	0:05 - 0:09	0:04 - 0:06	0:02 - 0:04				

PROCEDURES

°C = Degrees Celsius
°F = Degrees Fahrenheit
OAT = Outside Air Temperature
FP = Freezing Point

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

* During conditions that apply to aircraft protection for ACTIVE FROST
** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible
‡ Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, hail

**** TO USE THESE TIMES, THE FLUID MUST BE HEATED TO A MINIMUM TEMPERATURE OF 60°C (140°F) AT THE NOZZLE AND AT LEAST 1 LITER/M^2 (≈ 2 GALS/100FT^2) MUST BE APPLIED TO DEICED SURFACES**
SAE Type I fluid/water mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

CAUTIONS:
THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS. HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT, HIGH WIND VELOCITY, OR JET BLAST WILL REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT.
SAE TYPE I FLUID USED DURING GROUND DEICING/ANTI-ICING IS NOT INTENDED FOR AND DOES NOT PROVIDE PROTECTION DURING FLIGHT.
Effective: October 1, 2002

Figure B-2: TC TYPE I Holdover Time Guideline

TABLE 1S-3gm

SAE TYPE I[5] FLUID HOLDOVER GUIDELINES FOR WINTER 2002-2003

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes)							
°C	°F	Frost [2]	Freezing Fog	Light Snow [1]	Moderate Snow [1]	Freezing Drizzle [3]	Light Freezing Rain	Rain On Cold Soaked Wing	Other [4]
above -3	above 27	45	11 - 17	11 - 22[6]	6 - 11	9 - 13	2 - 5	2 - 5	
-3 to -10	27 to 14	45	6 - 10	6 - 13[6]	4 - 6	5 - 8	2 - 5	CAUTION : No holdover time guidelines exist	
below -10	below 14	45	5 - 9	4 - 8[6]	2 - 4				

°C = Degrees Celsius OAT = Outside Air Temperature

°F = Degrees Fahrenheit FP = Freezing Point

NOTES

1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m² (2 gal./100 ft²) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER

2 During conditions that apply to aircraft protection for ACTIVE FROST.

3 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

4 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.

5 Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

6 The light snow range is based on precipitation rates from 1.0 mm/hr to 0.3 mm/hr liquid water equivalent.

CAUTIONS:

- **The time of protection will be shortened in severe weather conditions, heavy precipitation or high moisture content. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when aircraft skin temperature is lower than OAT.**
- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **Fluids used during ground deicing do not provide ice protection during flight.**

APPENDIX C

CALCULATION OF PROBABILITIES OF UNDERESTIMATING SNOWFALL INTENSITY

CALCULATION OF PROBABILITIES OF UNDERESTIMATING SNOWFALL INTENSITY

To calculate the probability of underestimating snowfall intensity for each cell in the visibility table, it was assumed that snowfall rates occurring in a given visibility range follow a normal distribution. The probability of snowfall rates higher than those associated with a snowfall intensity (i.e. light snow) occurring is calculated by converting the distribution of rates to a standard normal distribution. The upper rate in the snowfall intensity range is converted to a standard normal distribution value by using the following formula:

$z = (x - \mu) / \sigma$, where x = upper rate limit for a given snowfall intensity
μ = mean of the rate distribution in a given visibility range
σ = standard deviation of the rate distribution in a given visibility range
z = z-score

When the calculated z-score is looked up in the standard normal distribution table, the probability of a rate occurring between the mean and the upper rate limit is returned (referred to below as the z-statistic). To calculate the probability that a rate above the upper rate limit will occur, the z-statistic is subtracted from 0.5. A visual representation of these calculations is shown in Figure C-1.

Calculations for the probabilities presented in the report are shown below.

1. BELOW -1°C

1.1 Probability of Heavy Snow Occurring when Moderate Snow Predicted

Snowfall Intensity:	Moderate	Z-Score:	1.81
Visibility Range:	>3/8 to 7/8 miles	Z-Statistic:	0.4649
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.035 (3.5%)
Mean Rate:	12.8 g/dm^2/h		
Standard Deviation:	6.9 g/dm^2/h		

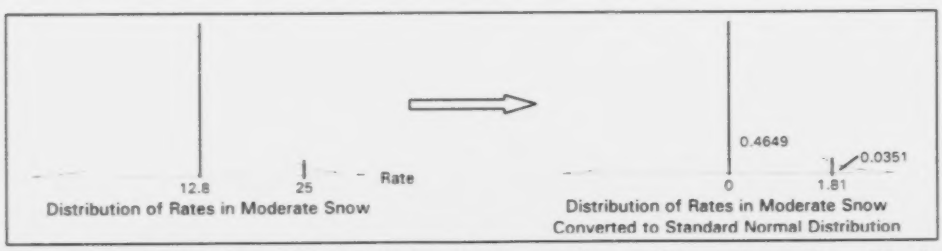

Figure C-1: Calculation of Probability of Heavy Snow Occurring when Moderate Snow Predicted

1.2 Probability of Moderate or Heavy Snow Occurring when Light Snow Predicted

Snowfall Intensity:	Light	Z-Score:	1.39
Visibility Range:	>7/8 to 2 miles	Z-Statistic:	0.4177
Upper Rate Limit:	10 g/dm^2/h	Probability:	0.082 (8.2%)
Mean Rate:	5.4 g/dm^2/h		
Standard Deviation:	3.3 g/dm^2/h		

1.2.1 Probability of Heavy Snow Occurring when Light Snow Predicted

Snowfall Intensity:	Light	Z-Score:	5.94
Visibility Range:	>7/8 to 2 miles	Z-Statistic:	0.5000
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.0 (0%)
Mean Rate:	5.4 g/dm^2/h		
Standard Deviation:	3.3 g/dm^2/h		

1.2.2 Probability of Moderate Snow Occurring when Light Snow Predicted

Probability = Probability (1.2) – Probability (1.2.1)
8.2% – 0.0%
8.2%

1.3 Probability of Light, Moderate or Heavy Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	1.22
Visibility Range:	> 2 miles	Z-Statistic:	0.3888
Upper Rate Limit:	4 g/dm^2/h	Probability:	0.111 (11.1%)
Mean Rate:	1.8 g/dm^2/h		
Standard Deviation:	1.8 g/dm^2/h		

1.3.1 Probability of Heavy Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	12.88
Visibility Range:	> 2 miles	Z-Statistic:	0.5000
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.0 (0.0%)
Mean Rate:	1.8 g/dm^2/h		
Standard Deviation:	1.8 g/dm^2/h		

1.3.2 Probability of Moderate Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	4.555
Visibility Range:	> 2 miles	Z-Statistic:	0.500
Upper Rate Limit:	10 g/dm^2/h	Probability:	0.0 (0.0%)
Mean Rate:	1.8 g/dm^2/h		
Standard Deviation:	1.8 g/dm^2/h		

1.3.3 Probability of Light Snow Occurring when Very Light Snow Predicted

Probability = Probability (1.3) – Probability (1.3.1) – Probability (1.3.2)
8.2% - 0.0% - 0.0%
8.2%

2. ABOVE -1°C

2.1 Probability of Heavy Snow Occurring when Moderate Snow Predicted

Snowfall Intensity:	Moderate	Z-Score:	2.51
Visibility Range:	>1/2 to 1 1/2 miles	Z-Statistic:	0.494
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.006 (0.6%)
Mean Rate:	10.2 g/dm^2/h		
Standard Deviation:	5.9 g/dm^2/h		

2.2 Probability of Moderate or Heavy Snow Occurring when Light Snow Predicted

Snowfall Intensity:	Light	Z-Score:	1.97
Visibility Range:	> 1 1/2 to 3 miles	Z-Statistic:	0.4756
Upper Rate Limit:	10 g/dm^2/h	Probability:	0.024 (2.4%)
Mean Rate:	4.1 g/dm^2/h		
Standard Deviation:	3.0 g/dm^2/h		

2.2.1 Probability of Heavy Snow Occurring when Light Snow Predicted

Snowfall Intensity:	Light	Z-Score:	6.967
Visibility Range:	> 1 1/2 to 3 miles	Z-Statistic:	0.500
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.0 (0.0%)
Mean Rate:	4.1 g/dm^2/h		
Standard Deviation:	3.0 g/dm^2/h		

2.2.2 Probability of Heavy Snow Occurring when Light Snow Predicted

Probability = Probability (2.2) – Probability (2.2.1)
2.4% – 0.0%
2.4%

2.3 Probability of Light, Moderate or Heavy Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	1.64
Visibility Range:	> 3 miles	Z-Statistic:	0.4495
Upper Rate Limit:	4 g/dm^2/h	Probability:	0.051 (5.1%)
Mean Rate:	2.0 g/dm^2/h		
Standard Deviation:	1.2 g/dm^2/h		

2.3.1 Probability of Heavy Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	19.17
Visibility Range:	> 3 miles	Z-Statistic:	0.500
Upper Rate Limit:	25 g/dm^2/h	Probability:	0.0 (0.0%)
Mean Rate:	2.0 g/dm^2/h		
Standard Deviation:	1.2 g/dm^2/h		

2.3.2 Probability of Moderate Snow Occurring when Very Light Snow Predicted

Snowfall Intensity:	Very Light	Z-Score:	6.667
Visibility Range:	> 3 miles	Z-Statistic:	0.500
Upper Rate Limit:	10 g/dm^2/h	Probability:	0.0 (0.0%)
Mean Rate:	2.0 g/dm^2/h		
Standard Deviation:	1.2 g/dm^2/h		

2.3.3 Probability of Light Snow Occurring when Very Light Snow Predicted

Probability = Probability (2.3) – Probability (2.3.1) – Probability (2.3.2)
5.1% – 0.0% – 0.0%
5.1%